

3. The majority of the chromium enhanced lines occur in the solar spectrum, though some appear to be missing.

4. Some of the Fraunhoferic lines correspond to metallic lines special to the spark spectrum, and lacking in the arc, and probably for this reason they were left unoriginated by Rowland.

“Air Resistance Encountered by Projectiles at Velocities up to 4500 Feet per Second.” By A. MALLOCK, F.R.S. Received November 3,—Read November 17, 1904.

The work done by Prof. Bashforth on the subject of air resistance is so well known that I need hardly refer to it except to say that his results have, with minor alterations, been confirmed by subsequent experimenters. The greater part of Professor Bashforth's work related to velocities under 2500 feet per second, and the object of the present experiments was to examine the co-efficient of air resistance at higher speeds.

In the years 1895–97, Major the Hon. T. F. Fremantle and Colonel H. Mellish made a series of experiments on the remaining velocities of the service .303 bullet by shooting into a ballistic pendulum from ranges varying from 12 up to 1000 yards. These experiments were made with great care, each bullet and charge being separately weighed, and from the results which they communicated to me I computed the co-efficient of resistance for velocities ranging from 2100 f.s. to 900 f.s. I suggested then that with light bullets we could probably extend the ballistic tables very considerably, using the pendulum to measure the velocity, and shortly after this we made some trials with various aluminium bullets. We found, however, that with cordite of the size used for the service charge of the .303 rifle a great part of the explosive was blown out unburnt when the light bullets were used. It was evident, therefore, that in order to get the velocities we required, a much finer cordite than the No. 3 of the service charge would have to be used. We found also that a considerable deposit of aluminium was left in the barrel after firing.

From various causes I have not been able to proceed with the experiments until the present year, when having obtained some cordite of diameter .01 inch, I again tried aluminium bullets, but the metallic fouling proved fatal to accurate and consistent results. I then tried shooting with lignum vitæ plugs which did very well up to velocities of about 2500 f.s., but at this velocity, sometimes, and generally at higher velocities, the plugs broke up under the action of centrifugal force. I again, therefore, reverted to aluminium, but on the bullets I made two small cannellures, fig. 1, which were filled with a composi-

tion of equal parts of black lead and tallow. These bullets answered admirably, and in July of the year I completed a series of experiments going up to velocities of 4500 f.s.

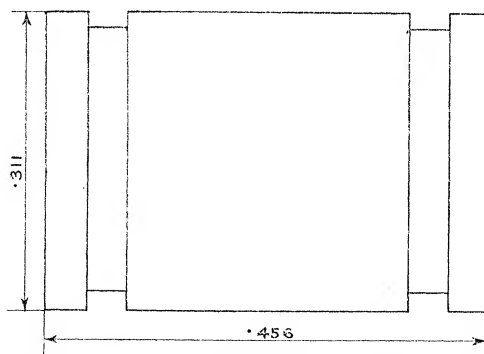


FIG. 1.—Aluminium shot used in air-resistance experiments. Scale five times actual size. Weight 23·3 grains.

The results of these experiments are given in the figs. 2 and 3, together with the results obtained from the shooting by Major Fremantle and Colonel Mellish, with the service bullet, and also, for comparison, Professor Bashforth's results.

Curve A, fig. 2, gives the velocities in feet per second, found at various ranges, and curve B, the loss of velocity in a distance of 5 yards. (It may be noted that at 4500 f.s. the retardation experienced by the light shot used was 205000 feet per second per second.) Curve A, fig. 3, gives the deduced resistance (in lbs. per square inch), encountered by the projectile, in terms of velocity.

To determine the resistance of an ogival-headed shot from the resistance experienced by a flat-headed shot moving with the same velocity, the resistance of the latter must be multiplied by a co-efficient, which is generally taken as $\frac{1}{2}$.

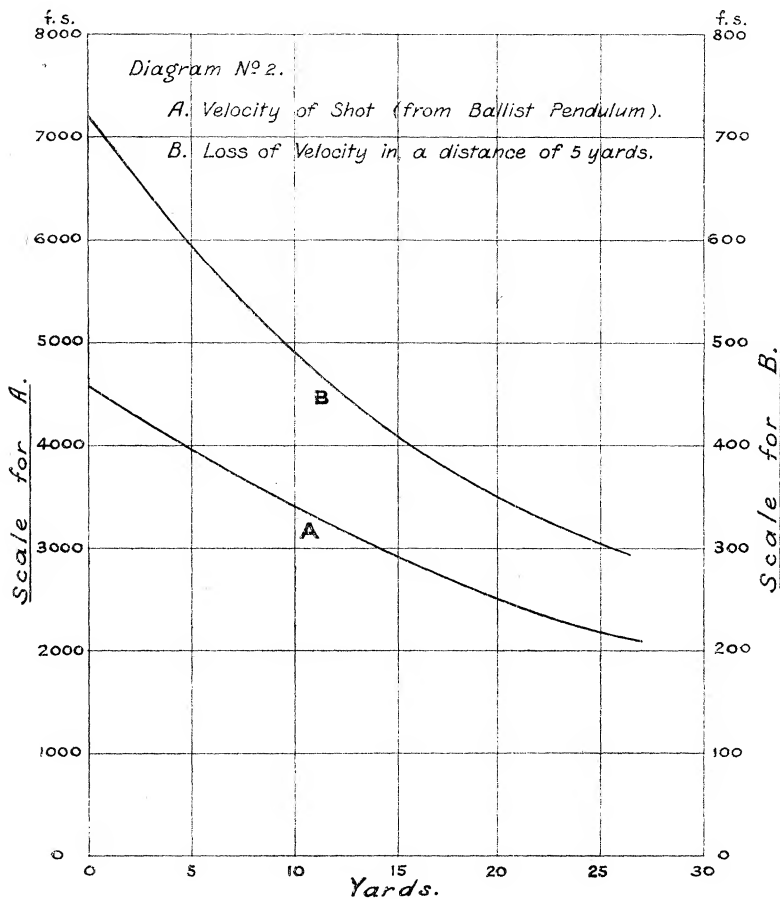
If the circular edges of the flat head are slightly rounded this value is nearly correct, but I have found by experiment that when the edges of the flat are quite sharp (as they were with the aluminium cylinders used), the co-efficient is rather less than half.*

In curve B, fig. 3, the co-efficient was taken as $\frac{1}{2\frac{1}{2}}$, and this curve represents, at any rate, very approximately, the resistance experienced by an ogival-headed shot. Curves C and D, fig. 3, give respectively, the results obtained from the experiments of Major Fremantle and Colonel Mellish, made with the .303 rifle, and by Professor Bashforth from his experiments with large guns.

* I hope to determine the true value more accurately than I have hitherto had time to do. Probably it is not a constant for all velocities, but approximates to a constant as the velocity increases.

When it is considered that the latter were obtained with projectiles weighing many pounds, and the others with shot of 23 and 215 grains respectively, the close agreement of the resistance curves is very

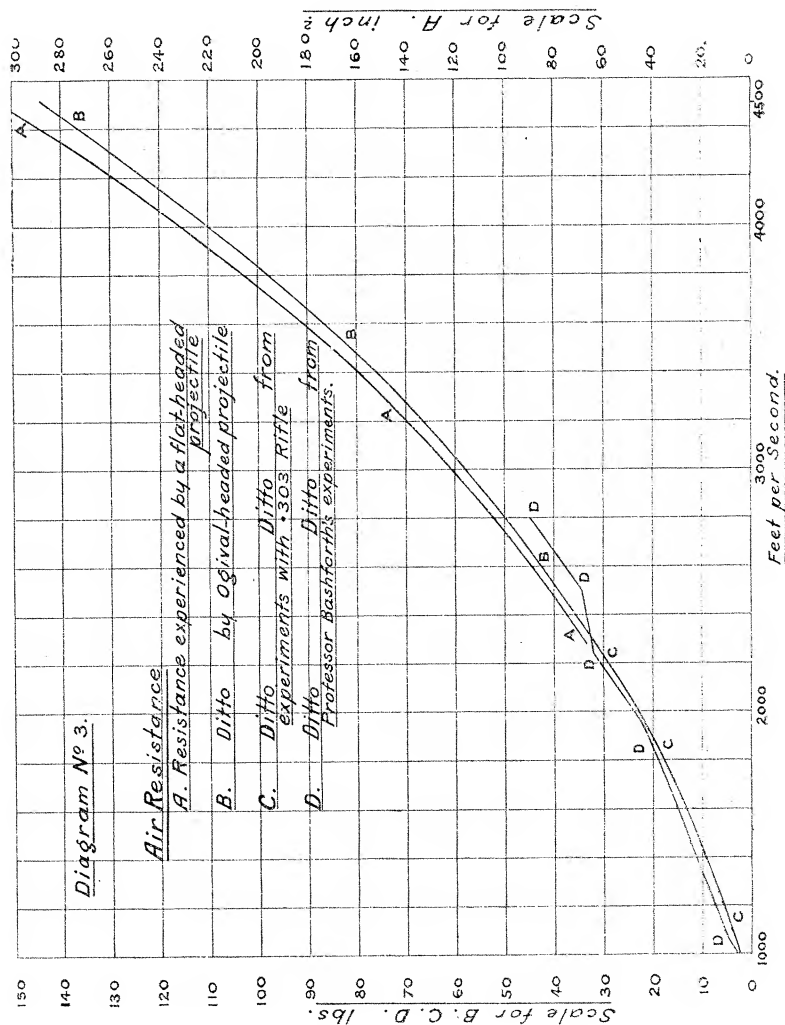
FIG. 2.



satisfactory, and shows in a striking way what can be done with small scale experiments when the proper scale of dynamic similarity is employed.

The extended resistance curve presents no peculiarities, although it can only be expressed at present by an arbitrary formula. But that this should be so is in itself rather remarkable, for it might well have been expected that the resistance would, for high velocities at least, be proportional to the pressure requisite to cause a gas to discharge through a hole in a thin-walled vessel at the speed of the shot.

FIG. 3.



The pressure in question is $\left(1 + \frac{\gamma - 1}{2} \frac{v^2}{a^2}\right)^{\frac{\gamma}{\gamma - 1}}$, where a is the velocity of sound, but the curve represented by this function and the curve of actual resistance do not even tend to approximate.